

Chapter 13

Titanium Tetrachloride Production

For purposes of this report, the titanium tetrachloride (TiCl_4) production sector consists of nine facilities that, as of September 1989, were active and reported generating a special mineral processing waste: chloride process waste solids. At one of these facilities (Timet at Henderson, NV) the TiCl_4 produced is used as feed material to manufacture titanium sponge metal. Two other titanium sponge producers, RMI and Ormet, reported no generation of the special waste and purchase rather than produce their mineral-related feedstock (TiCl_4).¹ Therefore, they are not addressed in this report.

At the remaining eight TiCl_4 facilities, the TiCl_4 produced is used as feed material to produce titanium dioxide (TiO_2) pigment by a process known as the "chloride process." Chloride process waste solids are generated during chlorination at all eight facilities. Adjacent to two chloride process facilities are two sulfate process TiO_2 pigment plants. The sulfate process wastes are not special mineral process wastes, therefore, these sulfate process plants and their wastes are not addressed further in this report. The data included in this chapter are discussed in additional detail in a technical background document in the supporting public docket for this report.

13.1 Industry Overview

Titanium tetrachloride is used as a feedstock to two major processes, production of titanium dioxide and titanium sponge. Titanium dioxide is used primarily as a pigment in the paper and paint industries;² titanium sponge, produced in much smaller volumes than TiO_2 , is used primarily in aircraft engines and airframes.³ In the chloride process, high titanium concentrates are reacted with chlorine gas at high temperature. The resulting titanium tetrachloride gas is condensed, purified by distillation, and then either oxidized to titanium dioxide or reduced to titanium sponge. The nine active facilities are located across the U.S., as shown in Exhibit 13-1.

Exhibit 13-1
Domestic Titanium Tetrachloride Producers

Owner	Location	Ore Type
E.I. duPont	Antioch, CA	Rutile
E.I. duPont	Edgemoor, DE	Ilmenite
E.I. duPont	New Johnsonville, TN	Ilmenite
E.I. duPont	Pass Christian, MS	Ilmenite
Kemira	Savannah, GA	Rutile
Kerr-McGee	Hamilton, MS	Synthetic Rutile
SCM	Ashtabula, OH	Rutile, S. African Slag
SCM	Baltimore, MD	Rutile, S. African Slag
TIMET	Henderson, NV	Rutile

¹ According to BOM sources, RMI is planning to build its own TiCl_4 facility, to be completed by year-end, 1991.

² The paper industry primarily uses TiO_2 produced by the sulfate process, which is not addressed in this report.

³ Lynd, Langtry, 1990. Personal communication, June 27, 1990.

Titanium metal and titanium dioxide production have steadily increased throughout the late 1980's. Between 1985 and 1989, titanium metal production increased by 12 percent from 21,000 metric tons to 24,000 metric tons. Production in 1989 was about 85 percent of capacity for the year. Demand for titanium mill products also increased, mainly because of the continued boom in orders for new commercial airliners and expansions in the pulp and paper and chemical industries. While imports for consumption dropped in 1989, exports of titanium metal increased. In 1989, two companies completed expansion of their capacity, bringing total U.S. capacity to approximately 28,000 metric tons. One company announced plans for further expansion from 5,400 metric tons per year to 8,000 metric tons per year by March 1991.⁴

U.S. production of titanium dioxide pigments increased approximately 8 percent in 1989 from 926,746 metric tons, to 1,007,000 metric tons, setting a new record-high level for the seventh consecutive year. Consumption eased slightly but was close to the record level reached in 1988. Domestic producers increased total capacity by approximately 125,000 metric tons, via process optimization as well as major expansions. Additional new capacity planned to be on-line in 1990-91 totals about 240,000 metric tons, which would increase total U.S. capacity to approximately 1,300,000 metric tons.⁵

Demand for titanium and titanium dioxide are closely tied to the overall economy. Future demands depend upon the health of the economy in the 1990s. In 1989, about 80 percent of the titanium metal consumed was used in jet engines, airframes, and space and missile applications, while about 20 percent was used in the chemical-processing industry, power generation, marine and ordnance, medical, and other non-aerospace applications. Also, in 1989 approximately 48 percent of the titanium dioxide consumed was used in paint, varnishes, and lacquers; the remaining use of titanium dioxide was divided between paper (24 percent), plastics (17 percent), rubber (2 percent), and others (9 percent).⁶ Industry sources indicate that world demand for titanium will grow at approximately 3 percent per year for pigment and 5 percent for metal for the next several years.⁷

Four of the titanium dioxide facilities are owned by one company, E.I. duPont de Nemours, two by SCM (which also operates a sulfate process plant), and one each by Kerr-McGee and Kemira (which also operates a sulfate process plant). Timet produces titanium sponge using the chloride process. All of the capacity and production data that were submitted by facility operators in response to the 1989 SWMPF Survey have been designated confidential by the individual respondents. Therefore, EPA has relied upon information from published sources to develop the necessary estimates for the analyses that follow.

Total titanium tetrachloride capacity is estimated to be 1.8 million metric tons per year. Approximately 41,000 metric tons of this capacity is the Henderson facility that primarily uses the product as a feedstock for titanium sponge production. The remaining capacity is at facilities whose primary use of the product is in production of titanium dioxide; a small portion of titanium tetrachloride produced at these facilities is sold for other uses. The Bureau of Mines estimates the long-term capacity utilization for these facilities to be 100 percent of capacity; 1988 capacity utilization at the Henderson facility was reportedly 87 percent of capacity or about 36,300 metric tons of titanium tetrachloride. The Bureau of Mines has reported that increased capacity of approximately 600,000 metric tons of titanium tetrachloride for use primarily in the production of titanium dioxide is expected by 1992.

Production of titanium tetrachloride involves chlorination of a titanium concentrate. The type of concentrate, however, may vary greatly between different companies and facilities, as shown in Exhibit 13-1. duPont's Antioch facility and the Kemira and SCM facilities use rutile, a high-grade concentrate containing approximately 95 percent titanium

⁴ Langtry E. Lynd, U.S. Bureau of Mines, Mineral Commodity Summaries, 1990 Ed., p. 180.

⁵ Ibid.

⁶ Ibid.

⁷ "Titanium: The Market is - in the Air," E&MJ, March 1990, p. 41.

dioxide.⁸ The SCM facilities may also use, in addition to rutile, a South African slag as a feedstock⁹ that contains approximately 85 percent TiO_2 .¹⁰ In addition to rutile, ilmenite, a lower grade mineral with TiO_2 content ranging from 45-65 percent, which is typically routed to the sulfate process, may also be used in the chloride process. Kerr-McGee's Mobile facility beneficiates Australian ilmenite to produce a synthetic rutile that is shipped to its Hamilton facility for chlorination. The three remaining duPont facilities use a high-grade ilmenite in a one-step "ilmenite-chlorination process."¹¹

Irrespective of the feedstock type or source, in a typical titanium tetrachloride operation, as shown in Exhibit 13-2, the ore is chlorinated in a fluidized-bed reactor in the presence of coke. The volatile metal chlorides are collected and the special waste, the non-volatile chlorides and the unreacted solids that remain, are discharged. The gaseous product stream is purified to separate the titanium tetrachloride from other chlorides. Acidic liquid waste streams, primarily ferric chlorides, are the primary liquid waste stream from this purification process; these are, however, not special wastes. Vanadium oxychloride, another low volume non-special waste, is not removed from titanium tetrachloride by distillation; rather it is separated by complexing this material with mineral oil followed by reduction with hydrogen sulfide, or by complexation with copper. The purified titanium tetrachloride is then oxidized to titanium dioxide or reduced to titanium sponge and the chlorine gas liberated by this process is typically recycled.¹² The non-volatile chlorides and the unreacted process solids that remain after the reaction in the fluidized-bed reactor are the special waste under study in this report. These solids, suspended in chloride process waste acids, are treated and discharged. As noted in the January 23, 1990 final rule (54 FR 2322), the slurried residue from the "chloride-ilmenite" process reportedly employed by three titanium tetrachloride production facilities are considered to be chloride process waste solids.

13.2 Waste Characteristics, Generation, and Current Management Practices

The special mineral processing waste generated by titanium tetrachloride processing is chloride process waste solids. The solids are typically generated in a slurry with waste acids; the solids in the slurry are particles with a diameter less than 0.02 mm (smaller than sand). The solids in this slurry are the special waste; the waste acid is not a special waste and is not discussed in this report.

Eight of the nine companies generating this waste requested that waste generation rate data be regarded as confidential business information; therefore, no facility-specific waste generation data are presented in this report. The aggregate annual industry-wide generation of chloride process waste solids by the nine facilities was approximately 414,000 metric tons in 1988, yielding a facility average of nearly 46,000 metric tons per year. Ratios of metric tons of chloride solids to metric tons of titanium tetrachloride produced range from 0.07 to 0.80 and average 0.208 for the sector.

Using available data on the composition of chloride process waste solids, EPA evaluated whether the waste solids exhibit any of the four characteristics of hazardous waste: corrosivity, reactivity, ignitability, and extraction procedure (EP) toxicity. Based on available information and professional judgment, the Agency does not believe the waste solids are corrosive, reactive, or ignitable, but some solids exhibit the characteristic

⁸ Lynd, 1988. Personal communication, Langtry Lynd, Titanium Commodity Specialist, U.S. Bureau of Mines, Washington D.C., August, 1988.

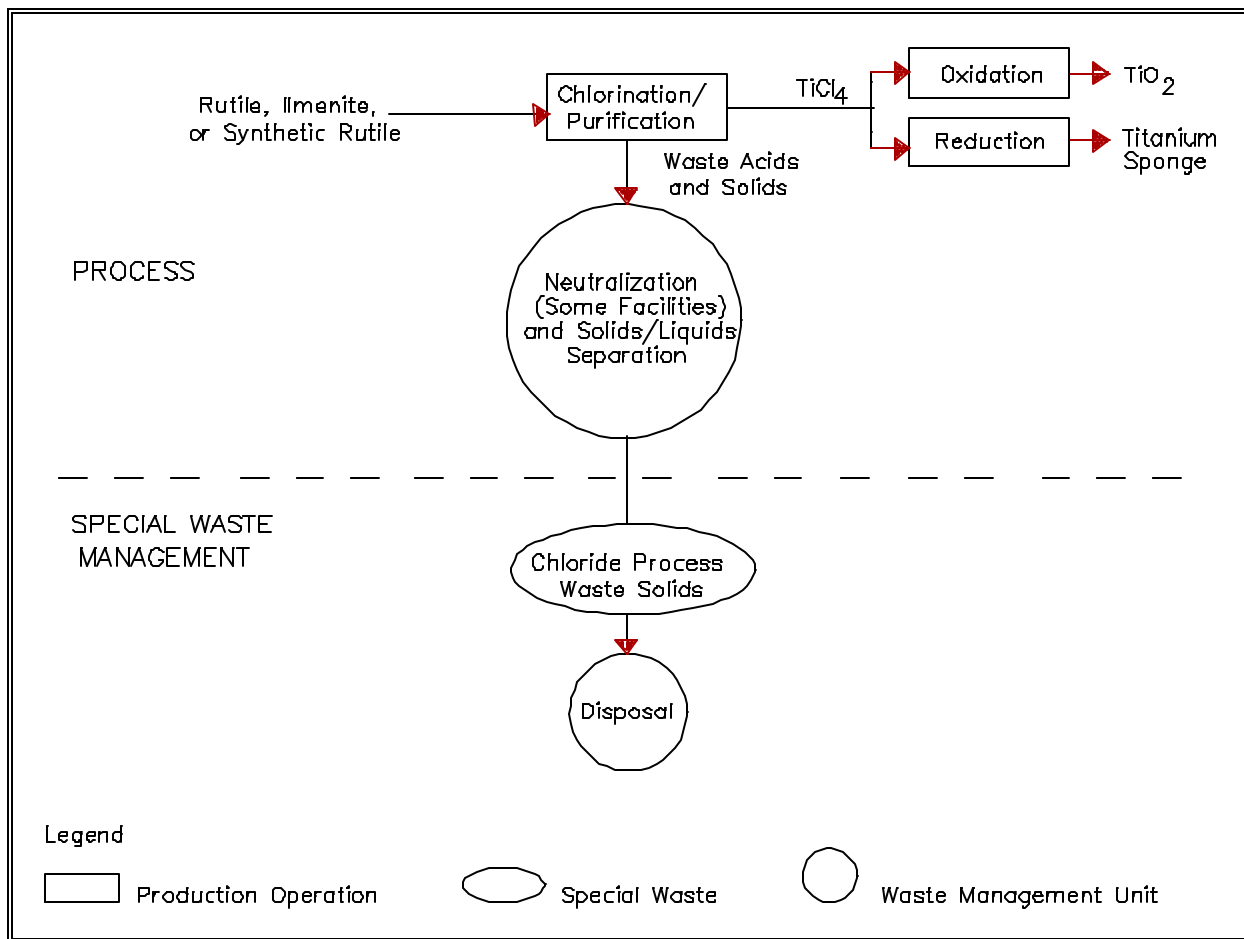
⁹ Ibid.

¹⁰ Bureau of Mines, 1985. Mineral Facts and Problems, 1985 Ed., p. 865.

¹¹ E.I. duPont de Nemours, 1989. Public comments from duPont addressing the 1989 proposed Reinterpretation of Mining Waste Exclusion (Docket No. -- MWRP00023); May 31, 1989, pp. 7-8.

¹² Environmental Protection Agency, 1984. Overview of Solid Waste Generation, Management, and Chemical Characteristics: Primary Antimony, Magnesium, Tin, and Titanium Smelting and Refining Industries. Prepared by PEI Associates for the U.S. EPA, December 1984.

Exhibit 13-2
Titanium Tetrachloride Production*



* And Related Activities (i.e., TiO₂ and Titanium Sponge Production)

of EP toxicity. EP leach test concentrations of all eight inorganic constituents with EP toxicity regulatory levels are available for waste solids from six of the nine facilities of interest (data on mercury concentrations were available from only three facilities). Of these constituents, only chromium and lead concentrations were found to exceed the EP toxicity levels. Of the 16 samples analyzed, concentrations of chromium exceeded the regulatory levels in only 3 samples, 1 each from the Edgemoor, New Johnsonville, and Henderson facilities. Chromium was present at concentrations in excess of the regulatory level by a factor ranging from 1.1 to 20. Lead concentrations exceeded the regulatory level in just 1 sample (from the Henderson facility) by a factor of 6.3. At one facility for which comparable SPLP test data are available, lead and chromium concentrations as determined by SPLP analyses also exceeded the EP toxicity regulatory levels by roughly the same margins as the EP test results.

The waste management practice used at titanium tetrachloride production facilities to manage chloride process waste solids is treatment of the stream as generated (i.e., in a slurry) and disposal of the solid residual (i.e., the special waste).

13.3 Potential and Documented Danger to Human Health and the Environment

This section addresses two of the study factors required by §8002(p) of RCRA: (1) potential danger (i.e., risk) to human health and the environment; and (2) documented cases in which danger to human health or the environment has been proved. Overall conclusions about the hazards associated with the waste solids are provided after these two study factors are discussed.

13.3.1 Risks Associated With Chloride Process Waste Solids

Any potential danger to human health and the environment from chloride process waste solids depends on the composition of the waste, the management practices that are used, and the environmental settings of the facilities where the waste solids are generated and managed.

Constituents of Concern

EPA identified chemical constituents in chloride process waste solids (as managed) that may present a hazard by collecting data on the composition of the solids and evaluating the intrinsic hazard of the chemical constituents.

Data on Chloride Process Waste Solids Composition

EPA's characterization of chloride process waste solids and leachate is based on data from two sources: (1) a 1989 sampling and analysis effort by EPA's Office of Solid Waste (OSW); and (2) industry responses to a RCRA §3007 request in 1989. These data provide information on the concentrations of 21 metals, chloride, fluoride, sulfate, and 3 radionuclides (radium-226, thorium-232, and uranium-238) in total and/or leach test analyses, and represent samples from 6 facilities.

Concentrations in samples of the chloride process waste solids are consistent for most constituents across all data sources and facilities. Arsenic concentrations in the solids, however, vary over five orders of magnitude across the facilities. Chemical concentrations in the waste solids leachate are generally consistent across the data sources, types of leach tests (i.e., EP and SPLP), and facilities.

Process for Identifying Constituents of Concern

As discussed in detail in Section 2.2.2, the Agency evaluated the data summarized above to determine if chloride process waste solids or leachate from the solids contain any chemical constituents that are intrinsically hazardous, and to narrow the focus of the risk assessment. The Agency performed this evaluation by first comparing the concentrations of chemical constituents to screening criteria that reflect the potential for hazards, and then by evaluating the environmental persistence and mobility of any constituents present in concentrations above the criteria. These screening criteria were developed using assumed scenarios that are likely to overestimate the extent to which the waste solid constituents are released and migrate through the environment to possible exposure points. As a result, this process identifies and eliminates from further consideration only those constituents that clearly do not pose a risk.

The Agency used three categories of screening criteria that reflect the potential for hazards to human health, aquatic organisms, and water quality (see Exhibit 2-3). Given the conservative (i.e., protective) nature of these screening criteria, contaminant concentrations in excess of the criteria should not, in isolation, be interpreted as proof of hazard. Instead, exceedances of the criteria indicate the need to evaluate the potential hazards of the waste solids in greater detail.

Identified Constituents of Concern

Exhibits 13-3 and 13-4 summarize the frequency with which the chemical and radioactive constituents of the chloride process waste solids and leachate exceed the risk screening criteria. Data are provided in the exhibits for all constituents that are present in concentrations that exceed a screening criterion.

Exhibit 13-3 identifies constituents in the waste solids that, based on total sample analysis results, were detected in concentrations above the screening criteria. Only 5 of the 28 constituents analyzed in the waste solids

exceed the screening criteria: arsenic, chromium, radium-226, thorium-232, and uranium-238. Of these constituents, chromium and radium-226 exceed the screening criteria most frequently, in at least 83 percent of all samples analyzed and at all facilities for which data are available. Chromium concentrations exceed the screening criteria by the widest margin, by as much as a factor of 75. Radium-226 levels as high as 24.5 pCi/g (5 times the screening criterion) were measured. In addition, maximum concentrations of 43 pCi/g of uranium-238 and 89 pCi/g thorium-232 exceed the screening criteria by factors of 4.3 and 8.9, respectively.¹³ The other constituents exceed the screening criteria by a factor of 15 or less. These exceedances indicate the potential for several types of impacts, as follows:

- Chromium, arsenic, thorium-232, and uranium-238 concentrations in the waste solids may pose a cancer risk of greater than 1×10^{-5} if dust from the solids is blown into the air and inhaled in a concentration that equals the National Ambient Air Quality Standard for particulate matter. As discussed in more detail in the next section, there is a moderate potential for dust to be blown into the air at the four facilities that manage the waste solids in waste piles and landfills.

Exhibit 13-3 Potential Constituents of Concern in Titanium Chloride Process Waste Solids^(a)

Potential Constituents of Concern	No. of Times Constituent Detected/No. of Analyses for Constituent	Human Health Screening Criteria ^(b)	No. of Analyses Exceeding Criteria/No. of Analyses for Constituent	No. of Facilities Exceeding Criteria/No. of Facilities Analyzed for Constituent
Chromium	14 / 14	Inhalation*	14 / 14	6 / 6
Thorium-232	12 / 12	Inhalation* Radiation ^(c)	1 / 12 1 / 12	1 / 1 1 / 1
Uranium-238	12 / 12	Inhalation* Radiation ^(c)	1 / 12 2 / 12	1 / 1 1 / 1
Radium-226	12 / 12	Radiation ^(c)	10 / 12	1 / 1
Arsenic	3 / 8	Ingestion* Inhalation*	2 / 8 2 / 8	1 / 6 1 / 6

- (a) Constituents listed in this table are present in at least one sample from at least one facility at a concentration that exceeds a relevant screening criterion. The screening criteria values used in this analysis are listed in Exhibit 2-3. Constituents that were not detected in a given sample were assumed not to be present in the sample.
- (b) Human health screening criteria are based on exposure via incidental ingestion and inhalation. Human health effects include cancer risk and noncancer health effects. Screening criteria noted with an "*" are based on a 1×10^{-6} lifetime cancer risk; others are based on noncancer effects.
- (c) Includes direct radiation from contaminated land and inhalation of radon decay products.

¹³ These radionuclide concentrations are similar to those reported in other sources. Specifically, "old sludge" from a titanium-chlorination process is reported to have 57 pCi/g uranium-238, 77 pCi/g thorium-232, and 25 pCi/gm radium-226 in Report No. 2 Natural Radioactivity Contamination Problems, Conference of Radiation Control Program Directors, Inc., August, 1981.

Exhibit 13-4
Potential Constituents of Concern in
Titanium Chloride Waste Solids Leachate^(a)

Potential Constituents of Concern	No. of Times Constituent Detected/No. of Analyses for Constituent	Screening Criteria ^(b)	No. of Analyses Exceeding Criteria/ No. of Analyses for Constituent	No. of Facilities Exceeding Criteria/ No. of Facilities Analyzed for Constituent
Iron	3 / 3	Resource Damage Aquatic Damage	3 / 3 2 / 3	3 / 3 2 / 3
Radium-226	2 / 2	Human Health*	2 / 2	1 / 1
Manganese ^(c)	4 / 4	Human Health Resource Damage	1 / 4 4 / 4	1 / 4 4 / 4
Chromium	8 / 16	Human Health Resource Damage Aquatic Ecological	4 / 16 7 / 16 5 / 16	3 / 6 5 / 6 5 / 6
Lead	5 / 16	Human Health Resource Damage Aquatic Ecological	4 / 16 5 / 16 4 / 16	4 / 6 5 / 6 4 / 6
Aluminum	3 / 3	Resource Damage Aquatic Ecological	1 / 3 2 / 3	1 / 3 2 / 3
Molybdenum	2 / 3	Resource Damage	2 / 3	2 / 3
Copper	2 / 3	Aquatic Ecological	2 / 3	2 / 3
Vanadium	3 / 4	Human Health Resource Damage Aquatic Ecological	1 / 4 2 / 4 1 / 4	1 / 4 2 / 4 1 / 4
Arsenic ^(c)	1 / 5	Human Health* Resource Damage	1 / 5 1 / 5	1 / 4 1 / 4
Silver ^(c)	1 / 4	Human Health Resource Damage Aquatic Ecological	1 / 4 1 / 4 1 / 4	1 / 4 1 / 4 1 / 4
Nickel	3 / 4	Human Health Resource Damage Aquatic Ecological	1 / 4 1 / 4 1 / 4	1 / 4 1 / 4 1 / 4
Thallium ^(c)	1 / 4	Human Health	1 / 4	1 / 4
Antimony	1 / 3	Human Health	1 / 3	1 / 3
Selenium ^(c)	1 / 5	Resource Damage Aquatic Ecological	1 / 5 1 / 5	1 / 4 1 / 4
Cobalt ^(c)	1 / 4	Resource Damage	1 / 4	1 / 4

- (a) Constituents listed in this table are present in at least one sample from at least one facility at a concentration that exceeds a relevant screening criterion. The screening criteria values used in this analysis are listed in Exhibit 2-3. Constituents that were not detected in a given sample were assumed not to be present in the sample. Unless otherwise noted, the constituent concentrations used for this analysis are based on EP leach test results.
- (b) Human health screening criteria are based on cancer risk or noncancer health effects. "Human health" screening criteria noted with an "*" are based on a 1×10^{-5} lifetime cancer risk; others are based on noncancer effects.

- (c) Data for this constituent are from SPLP leach test results.

- Arsenic concentrations in the waste solids could pose a cancer risk of more than 1×10^{-5} if a small quantity of the solids is incidentally ingested on a routine basis (which could occur if access to closed waste management units is not restricted or if the solids are used off-site in an unrestricted manner that allows children to come into direct contact with the waste).
- The concentrations of thorium-232, uranium-238, radium-226, (which were analyzed for in samples from only one facility) and other members of the uranium and thorium decay chains could pose a radiation hazard if the waste solids are allowed to be used in an unrestricted manner. For example, direct radiation doses and doses from the inhalation of radon decay products could be unacceptably high if the solids were to be used as fill material around homes.

Of the 25 constituents analyzed in the waste solids leachate, 16 were present in concentrations that exceed the screening criteria (see Exhibit 13-4). Among these constituents, chromium, copper, iron, lead, radium-226, manganese, and molybdenum concentrations in the leachate exceed the screening criteria most frequently and at the greatest number of facilities. Constituents present in concentrations that exceed the screening criteria by a factor of 10 or more include: aluminum, arsenic, chromium, iron, lead, manganese, molybdenum, nickel, vanadium, silver, and thallium. Measured concentrations of arsenic, chromium, iron, lead, manganese, vanadium, and silver also occasionally exceed the screening criteria by a factor of 100 or more. Lead concentrations in the leachate exceed the screening criteria by the widest margin (up to a factor of 625), and as discussed in section 13.2, lead and chromium were measured in concentrations that exceed the EP toxicity regulatory levels. These exceedances indicate the potential for the following types of impacts under the following conditions:

- Concentrations of arsenic, antimony, chromium, lead, manganese, nickel, radium-226, vanadium, silver, and thallium in the leachate exceed the human health screening criteria. This means that if the leachate migrates to drinking water sources with less than ten-fold dilution, long-term ingestion of untreated drinking water may cause adverse health effects. The diluted arsenic and radium-226 concentrations may cause a cancer risk of more than 1×10^{-5} .
- If the leachate migrates to surface or ground water with less than ten-fold dilution, the resulting concentrations of several constituents could render the water unsuitable for certain uses without prior treatment (i.e., cause water resource damages). Specifically, the diluted concentrations of arsenic, chromium, iron, lead, manganese, selenium, and silver may exceed the drinking water maximum contaminant levels, rendering the water unfit for human consumption. The diluted concentrations of aluminum, cobalt, molybdenum, nickel, and vanadium may exceed irrigation guidelines, rendering the water less desirable for use for agricultural purposes.
- Concentrations of aluminum, chromium, copper, iron, lead, nickel, selenium, silver, and vanadium in the leachate may present a threat to aquatic organisms if the leachate migrates (with less than 100-fold dilution) to surface waters.

These exceedances do not prove that the waste solids pose risk to human health and the environment, but rather indicate that the solids may present a hazard under very conservative, hypothetical exposure conditions. To examine the hazards associated with this waste in greater detail, the Agency proceeded to the next step of the risk analysis to evaluate the actual release, transport, and exposure conditions at the plants that actively generate and manage the waste solids.

Release, Transport, and Exposure Potential

The following analysis considers the baseline hazards of the waste as it was generated and managed at the nine titanium tetrachloride producing facilities in 1988. This evaluation does not assess the hazards of off-site use or disposal of the waste solids because the solids are never utilized managed off-site (nor are they likely to be in the near future). In addition, the analysis does not consider the risks associated with potential future changes in waste management practices or population patterns, because of a lack of adequate information on possible future conditions.

Ground-Water Release, Transport, and Exposure Potential

EPA and industry test data show that several constituents are capable of leaching from the chloride process waste solids in concentrations above the screening criteria. Given the low-pH conditions that are expected to exist, a large number of these constituents will be relatively mobile in ground water, including antimony, arsenic, chromium, copper, cobalt, iron, lead, manganese, nickel, selenium, silver, and thallium. Of these constituents, arsenic, chromium, iron, lead, manganese, and silver pose the greatest potential ground-water threat, considering their concentrations in the leachate relative to the screening criteria. Key factors that influence the potential for these constituents to cause ground-water impacts at each facility are summarized in Exhibit 13-5.

The waste solids are managed in surface impoundments and/or settling ponds at the eight facilities that did not declare their management techniques as confidential. These eight facilities are located in Antioch, CA, Edgemoor, DE, Hamilton, MS, Ashtabula, OH, New Johnsonville, TN, Pass Christian, MS, Henderson, NV, and Savannah, GA. At these sites, the waste solids are discharged as a slurry to the impoundments, where they settle to the bottom as a sludge. The standing liquid that is held on top of the settled solids provides a force that may drive contaminants from the solids to the subsurface. In this situation, the potential for release depends on the design features of the impoundments, the depth to ground water, and the permeability of the earth materials beneath the impoundments; the potential for exposure to contamination (if it occurs) depends on the surrounding ground-water use patterns. Considering these factors, which are summarized on a site-specific basis in Exhibit 13-5, the eight sites with impoundments can be grouped into three categories:

- There is a relatively high potential for ground-water contamination and subsequent exposure at the Hamilton facility. There are no known controls (e.g., liner or leachate collection systems) on the impoundments, the ground water is moderately shallow (roughly 6 meters deep), the substrate beneath the impoundments is a permeable sand, and there appears to be a drinking water well within 700 meters downgradient. This well, however, is on the opposite side of McKinley Creek from the impoundments, and thus may not receive full contaminant loadings from the impoundments (due to ground-water discharge to the creek).
- The potential for ground-water release and exposure is moderate at the Ashtabula and Savannah facilities. At Ashtabula, the on-site impoundment is underlain by in-situ clay and recompacted local clay, the ground water is moderately shallow (6 meters deep), the subsurface is mainly impermeable silt and clay, and the nearest downgradient drinking water well is roughly 800 meters away. Although the impoundment at Savannah is equipped with a leachate collection system, the ground water is shallow (3 meters deep), the subsurface is mainly a permeable sand, and there appears to be a drinking water well within 200 meters downgradient.
- The potential for release to ground water is relatively high at the Antioch facility, but the potential for exposure to any ground-water contamination appears low. There are no known controls on the on-site impoundments, the ground water is very shallow (1 meter deep), and the subsurface is a permeable sand. However, the aquifer does not contain freshwater and does not appear to be used in the area.
- The potential for ground-water release and exposure at the facilities in Edgemoor, New Johnsonville, Pass Christian, and Henderson appears relatively low. At these facilities, the impoundments are equipped with either in-situ clay, recompacted clay, or, as is the case at Henderson, synthetic liners. The depth to useable ground water ranges from 6 to 48 meters, the underlying earth materials are generally sandy, and there are no known uses of the ground water within 1.6 km (1 mile).

Exhibit 13-5
Summary of Release, Transport, and Exposure Potential
for Chloride Process Waste Solids

Facility	Release, Transport, and Exposure Potential	Proximity to Sensitive Environments
ANTIOCH	<p>Groundwater: No information on the engineered controls for small on-site settling pond, but because of the relatively permeable subsurface (90% sand), releases to the very shallow aquifer (0.6 to 1.2 meters) are possible. Exposures unlikely because the aquifer does not contain fresh water and is not used in the area.</p> <p>Surface water: Moderate annual precipitation (41 cm/year) and gently sloped land (0-2%) limit potential for storm water to cause overflowing from the settling pond. Migration of contaminants to San Joaquin River (located 920 meters away) via recharge to ground water could occur; potential for ecological impacts and resource damage is low due to the large assimilative capacity (5,000 mgd) of the river; moderate potential for current human health risks because there is an intake for drinking water located within 100 meters downstream of the facility.</p> <p>Air: Releases unlikely because waste solids remain submerged beneath liquid.</p>	Located within 1.6 km of a wetland and within 2.6 km of an endangered species habitat
EDGE MOOR	<p>Groundwater: Releases limited by recompacted local clay liners. Even if releases to shallow ground water (6 meters) occur, there are no users of the ground water within 1.6 km down gradient.</p> <p>Surface water: Routine overland releases limited by stormwater run-on/run-off controls; because of high precipitation (104 cm/year), the steep topographic slope (6 to 12%), and possible floods (facility located in 100-year floodplain), episodic overflow and overland runoff could occur. The Delaware River is located very close (10 meters) from the boundary of the facility, but is not used as a source of drinking water within 24 km downstream.</p> <p>Air: Releases unlikely because waste solids remain submerged beneath liquid.</p>	Located in a 100-year floodplain
NEW JOHNSONVILLE	<p>Groundwater: Five surface impoundments are underlain by recompacted local clay while the single landfill is not lined. Although there is relatively high precipitation (126 cm/yr) and recharge (28 cm/yr), significant releases to ground water unlikely because water table is moderately deep (11 m) and useable ground water is even deeper (49 m). No known users of the aquifer within 1.6 km.</p> <p>Surface water: Although there is high precipitation in the area, potential for erosion from the landfill and overflow from the surface impoundments is limited by moderate topographic slope (2-6%) and stormwater run-on/run-off controls; releases via recharge to ground water could occur to the Tennessee River located 30 meters away, but its very large flow (42,000 mgd) yields significant dilution capacity; there is a downstream drinking water intake supplying approximately 400 people.</p> <p>Air: Releases from landfill not controlled by dust suppression; small number of wet days (98 days/year) and average wind speeds up to 3.4 m/s could lead to airborne dust. There are no residences within 1.6 km of the facility.</p>	Located within 1 mile of a National Park

Exhibit 13-5 (cont'd)
Summary of Release, Transport, and Exposure Potential
for Chloride Process Waste Solids

Facility	Release, Transport, and Exposure Potential	Proximity to Sensitive Environments
PASSCHRISTIAN	<p>Ground water: Although two surface impoundments, one settling pond, and one landfill are underlain by recompacted clay, releases may occur due to the high precipitation (160 cm/year), moderate net recharge (15 cm/year), and shallow water table (2 meters); however, the useable aquifer is deep (26 m) and there are no drinking water wells within 1.6 km downgradient of the facility.</p> <p>Surface water: Although facility is located in high precipitation area, overland runoff limited by stormwater run-on/run-off controls and gentle topographic slope (0-2%). Contaminants could migrate to the St. Louis Bay (274 meters away) via recharge to shallow ground water (2 meters deep).</p> <p>Air: Releases from landfill not controlled by dust suppression; small number of wet days (92 days/year) and average wind speeds up to 4.2 m/s could lead to airborne dust and inhalation exposures at closest residence 60 meters from the facility, as well as potential food chain exposures through deposition of particulates on agricultural fields within 1.6 km; a total of 30 people live within 1.6 km.</p>	Located in a 100-year floodplain and within 1.6 km of a wetland
SAVANNAH	<p>Ground water: Surface impoundment is equipped with leachate collection system, but is without a liner; waste pile is without any ground-water controls; potential for releases to ground water because of high precipitation (126 cm/year), moderate net recharge (15.3 cm/year), permeable subsurface (85% sand), and shallow useable aquifer (3 meters). Potential drinking water exposure could occur at municipal well 183 meters downgradient.</p> <p>Surface water: Overland run-off limited by stormwater run-on/run-off controls at both management units, and gentle topographic slope (0-2%). Contaminants could migrate to nearby Savannah River (90 meters) via ground-water recharge; no consumptive uses of the river within 24 km, and releases to surface water pose low aquatic ecological risks (because of the river's large dilution capacity, i.e., 8,000 mgd).</p> <p>Air: Air releases not controlled by dust suppression; moderate number of wet days (111 days/year), average wind speeds up to 3.4 m/s, and low height of waste pile (1.2 meters) may limit airborne dust to an extent; potential inhalation exposures could occur at closest residence within 100 meters of the facility.</p>	Located within 1.6 km of a wetland and the Savannah National Wildlife Refuge
HAMILTON	<p>Ground water: Releases from two large impoundments to the shallow usable aquifer (6 meters) could occur because of the fairly permeable subsurface (93% sand) and moderate net recharge (13 cm/year); impoundments border McKinley Creek and ground water may discharge directly into the creek without being used; however, if ground water passes beneath the creek, a well 700 meters downgradient may become contaminated.</p> <p>Surface water: Overland release from the impoundments is limited by stormwater run-on/run-off controls, and gentle topographic slope (0-2%); releases to nearby McKinley Creek (60 meters) could occur by recharge from ground water; low potential for human health or ecological risks because of the large flow of the creek (5,000 mgd); a drinking water intake exists 1,700 meters downstream.</p> <p>Air: Releases unlikely because waste solids remain submerged beneath liquid.</p>	Located within 1.6 km of a wetland

Exhibit 13-5 (cont'd)
Summary of Release, Transport, and Exposure Potential
for Chloride Process Waste Solids

Facility	Release, Transport, and Exposure Potential	Proximity to Sensitive Environments
ASHTABULA	<p>Groundwater: Two surface impoundments are underlain by in-situ clay and recompact local clay that could prevent releases to ground water; if releases were to occur to the shallow aquifer (6 meters), potential drinking water exposures could occur at municipal well 800 meters downgradient.</p> <p>Surface water: Overland releases from the impoundments are limited by stormwater run-on/run-off controls and gentle topographic slope (0-2%); releases to nearby Lake Erie (700 meters) could occur by recharge to ground water; releases to the lake should be diluted significantly.</p> <p>Air: Releases unlikely because waste solids remain submerged beneath liquid.</p>	Located in a fault zone
BALTIMORE	<p>Ground water: All specifications on the two management units are confidential; moderately shallow ground water (9 m) brackish and not used; useable aquifer at 137 m protected by clay confining layer; no consumptive uses of the aquifer within 1.6 km of the facility.</p> <p>Surface water: No information on controls to prevent overland run-off, but potential for run-off could be significant because of high precipitation and relatively impermeable subsurface; migration of contaminants via recharge to shallow ground water that discharges to the closest surface water, i.e., Chesapeake Bay (490 meters) could occur.</p> <p>Air: Moderate number of wet days (103 days/year) could limit airborne releases to an extent; if the high wind speeds (average wind speeds up to 5.3 m/s) lead to airborne dust, potential exposures would be minimal because there are no residences within 1.6 km of the facility.</p>	Located within 1.6 km of a wetland
HENDERSON	<p>Groundwater: Surface impoundment has a synthetic liner but waste pile has no ground-water controls; depth to useable aquifer is not known but releases are limited by low precipitation (11 cm/year), and zero net recharge; no drinking water wells within 1.6 km downgradient.</p> <p>Surface water: Overland run-off limited by stormwater run-on/run-off controls, gentle topographic slope (2-6%), and low annual precipitation; nevertheless, the facility is located in a 100-year floodplain and episodic release could occur in a flood event. A lake (Las Vegas Wash) is located just 46 meters from the facility and potential human health exposures could occur at a drinking water intake 1100 meters from the facility.</p> <p>Air: Releases not controlled by dust suppression; very small number of wet days (21 days/year), height of waste pile (6 meters), and average wind speeds into 4.1 m/s could lead to airborne dust and inhalation exposures at closest resident 90 meters from the facility. Population within 1.6 km of the facility is 5,000.</p>	Located in a 100-year floodplain, and within 1.6 km of an wetland and the Lake Mead National Recreation Area

The four facilities located in New Johnsonville, TN, Pass Christian, MS, Henderson, NV, and Savannah, GA periodically dredge solids from the impoundments described above and place the dried solids in on-site landfills or waste piles. In general, the potential for contaminants to leach from these units into ground water is significantly lower than the potential for release from the impoundments. In waste piles or landfills, the hydraulic head that may force contaminants out of the impoundments has been removed and the potential for release is limited by the amount of rainfall that is able to infiltrate through the pile or landfill and into the ground. Considering the site-specific factors summarized in Exhibit 13-5:

- There is a moderate potential for release from the waste pile and landfill at the Savannah and Pass Christian facilities. At both sites, the waste management unit is not lined, net recharge is moderate (15 cm/yr), and ground water is shallow (2 to 3 meters deep). There also appears to be a drinking water well within 200 meters downgradient of the Savannah facility. The useable aquifer at Pass Christian is 26 meters deep, and there appears to be no downgradient wells that withdraw water from this aquifer within 1.6 km (1 mile).
- The potential for significant releases from the piles/landfills at the New Johnsonville and Henderson facilities is low. Although the net infiltration of water into the ground at New Johnsonville is moderate (28 cm/year), the ground water is relatively deep (11 m to the water table and 48 meters to a useable aquifer) and contaminants leaching from the landfill at this site will likely be predominantly bound up in the soil in the unsaturated zone. The Henderson facility is located in a very arid area with low precipitation (around 11 cm/yr) and essentially no net recharge. Therefore, there is virtually no water available to seep through the pile at this site and carry contaminants to the subsurface.

The type and characteristics of the waste management unit(s) at the facility in Baltimore, MD are confidential. However, based on the depth to useable ground water¹⁴ (137 meters), impermeable subsurface (70% clay), and current aquifer-use patterns in the vicinity of this facility (virtually all water is provided by the city water supply, the sources of which are several distant reservoirs), the potential for release to potable ground water and subsequent human exposure appears minimal.

Surface Water Release, Transport, and Exposure Potential

In theory, contaminants from chloride process waste solids could enter surface waters by two main pathways: (1) migration of leachate through ground water that discharges to surface water; and (2) direct overland (stormwater) run-off in either a dissolved form or in the form of solid particles. Based on the available data on the waste solids composition, the solids contain a number of constituents in concentrations that are above the screening criteria. Site-specific factors that influence the potential for these contaminants to migrate to surface waters are summarized in Exhibit 13-5.

Direct overland run-off of the waste contaminants when managed in surface impoundments is limited to a large extent by run-on/run-off controls at each site, and appears possible only in the event of a flood at the Edgemoor, Pass Christian, and Henderson facilities (which are located in 100-year floodplains). It is more likely that waste solids contaminants managed in surface impoundments might migrate to surface water by leaching into ground water that discharges to surface water. Considering the ground-water release potential (as discussed in the section above) and the proximity of the plants to surface waters, the potential for release of waste solids contaminants from impoundments to surface water appears greatest at the Antioch, Hamilton, Ashtabula, Edgemoor, and Savannah facilities. The distances between these facilities and the nearest surface water bodies ranges from 10 to 880 meters. However, all of these water bodies are very large and have flows capable of readily diluting small contaminant loads from ground water (e.g., the annual average flows of rivers nearest the Antioch, Hamilton, and Savannah facilities are 5,000 mgd or greater, and the Ashtabula facility is adjacent to Lake Erie). Therefore, based on all of these factors, there is a minimal potential for the solids to cause significant surface water impacts when managed in surface impoundments.

¹⁴ There is a shallow aquifer less than 10 meters from the surface, but due to salt water intrusion, this aquifer is no longer suitable for use as a water supply.

When managed in piles and landfills, the waste solids are more likely to migrate into surface waters via stormwater erosion (as discussed in the preceding section, there is only a moderate potential for contaminants to seep into ground water from these units, and this potential exists at only two facilities). The physical form of the waste solids should not limit the erosion and subsequent entrainment of solids in run-off. Particles that are 0.1 mm or less in size tend to be appreciably erodible, and a large fraction of the waste solids are expected to be in this size range (chloride process waste solids particles are typically on the order of 0.02 mm in diameter). Again, only the New Johnsonville, Pass Christian, Henderson, and Savannah facilities manage the waste solids in piles or landfills. The potential for waste solids contaminants from these sites to cause significant surface water impacts is limited by several factors, as summarized below:

- Although the New Johnsonville and Savannah facilities are located in areas with high precipitation (126 cm/year), routine overland runoff from the on-site waste pile and landfill is limited by stormwater run-on/run-off controls and moderately gentle slopes (less than 6 percent). Moreover, the potential for surface water damages is low because the Tennessee and Savannah Rivers located within 100 meters of the facilities have large capacities to assimilate contaminant inflows (i.e., average flows of 42,000 and 8,000 mgd, respectively).
- Although the Pass Christian facility is only 30 meters from the St. Louis Bay, routine releases to the bay from the on-site landfill via either ground-water discharge or stormwater erosion are likely to be readily assimilated in the bay's large flow.
- Routine overland releases are limited at the Henderson facility by stormwater run-on/run-off controls, and the low precipitation (11 cm/year) and gentle topographic slope (0-2 percent) in the area. However, the facility is located in a 100-year floodplain and is only 45 meters from a lake (Las Vegas Wash). Episodic overland run-off of contaminants from the waste solids to the lake is possible in the unlikely event of a flood. Any contaminants reaching the lake in this manner, if not sufficiently diluted, could endanger aquatic life, restrict potential future uses of the lake, and pose a current health risk via a drinking water intake 1,100 meters from the facility.

At the facility in Baltimore, MD, it is possible for contaminants to leach into the shallow ground water located 9 meters below the surface and migrate into the Chesapeake Bay located 500 meters downgradient. Because the precipitation in this area is high (108 cm) and the subsurface is relatively impermeable, overland run-off due to surface erosion is also possible at this facility. If contaminants did reach the bay via either of these routes, they would likely be rapidly diluted by the bay's large flow.

Air Release, Transport, and Exposure Potential

Only windblown dust particles from the chloride process waste solids are of concern for the air pathway because all hazardous constituents of the waste are nonvolatile inorganics. The potential for dust to be blown into the air from the surface impoundments and solids settling ponds is virtually non-existent because the waste solids are submerged beneath liquids. When the settled solids and sludge are dredged, dried, and accumulated in waste piles or landfills, airborne dust releases from these units could be possible. If releases were to occur, chromium, and to a lesser extent, arsenic, thorium-232, and uranium-238 in the waste solids particles could cause adverse health effects if inhaled, depending on the amount of dust emitted and the proximity of receptors.

Release of dust particles from the landfills and waste piles to the air is possible because the waste solids can be 20 micrometers (μm) or less in diameter (smaller than sand). In general, particles that are $\leq 100 \mu\text{m}$ in diameter are wind suspendable and transportable. Within this range, however, only particles that are $\leq 30 \mu\text{m}$ in diameter can be transported for considerable distances downwind, and only particles that are $\leq 10 \mu\text{m}$ in diameter are respirable. Therefore, a significant amount of the waste solids are expected to be suspendable and transportable, and a small fraction is expected to be respirable.

For the chloride process waste solids accumulated in waste piles and landfills, site-specific factors affecting the potential for airborne release and exposure include the exposed or uncovered surface area of the units, wind speeds, number of days with precipitation (which affects the moisture content of the waste solids), the use of dust suppression controls, and the proximity of the units to potentially exposed populations. These factors are summarized on a site-

specific basis in Exhibit 13-5 for the four facilities that manage the solids in waste piles and landfills (New Johnsonville, Pass Christian, Savannah, and Henderson).

Considering these factors at the two sites with landfills, located in New Johnsonville, TN and Pass Christian, MS, airborne releases of dust are considered possible at both sites, but it appears that people could be exposed to such releases at only the Pass Christian facility. Neither facility practices dust suppression and the number of days with rain, which suppresses dust naturally, is small at both facilities (92 and 98 days/yr). As a result, the exposed surface of the waste solids is expected to be dry most of the time. It is not known if inactive portions of the landfill are covered, but active portions are certainly uncovered and exposed to the wind. Although there are short term gusts of stronger winds, average wind speeds range up to 3.4 and 4.2 m/s at these facilities, which are strong enough to suspend the fine fraction of the solids. If such releases occur, the potential for inhalation exposures could be significant at the Pass Christian facility because there is at least one residence within a distance of 60 meters. However, the population within a mile of the facility is small (30 people). Furthermore, at the Pass Christian facility, there is also a potential for food chain exposures through deposition of particles on food crops in the agricultural fields within a mile of the facility. There is no known population within a mile of the New Johnsonville facility.

At the two facilities that manage the waste solids in piles, the potential for airborne releases and exposures is high at the Henderson, NV facility and moderate at the Savannah, GA facility, based on the following factors:

- At the Henderson facility, the waste solids pile covers 1.5 acres, is 6 meters high, and is assumed to be uncovered. The waste solids in the pile are probably dry most of the time because no dust suppression is conducted and the number of days with precipitation is very small (21 days/yr). Average wind speeds at this facility range up to 4.1 m/s, although there are certainly short-term gusts of stronger winds. If significant quantities of dust are blown into the air, inhalation exposures could occur at the nearest residence, located only 90 meters from the facility. The total population within 1.6 km (1 mile) is 5,000.
- The waste solids pile at the Savannah facility covers an area of 1.5 hectares (3.7 acres), is 1.2 meters high, and is assumed to be uncovered. Although the facility does not practice dust suppression, there is a moderate number of days with rain (111 days/year) that should help keep the surface of the waste solids moist part of the time. Annual average wind-speeds range up to 3.4 m/s, which is sufficient to cause wind erosion of fine particles. If released, the wind-blown dust could lead to inhalation exposures at the closest residence (400 meters from the facility), as well as exposures to the 500 people that live within 1.6 km (1 mile).

Proximity to Sensitive Environments

As summarized in Exhibit 13-5, all nine titanium tetrachloride/dioxide facilities are located in environments that are either vulnerable to contamination or have high resource value that may warrant special consideration. In particular:

- The Antioch facility is located within 2.6 km (1.6 miles) of the critical habitat of an endangered species, the Antioch Dunes Evening Primrose. Based on the conditions at this site, the titanium waste solids at the Antioch facility could conceivably be a source of ground-water contamination, but are not likely to be a significant source of surface water or air contamination (see the preceding analysis). Considering the distance between the site and the critical habitat, the waste solids should not pose a significant hazard to the endangered species.
- The Edgemoor, Henderson, and Pass Christian facilities are located in 100-year floodplains, which creates the potential for large, episodic releases of the waste solids in the unlikely event of a large flood.
- The Henderson, Antioch, Hamilton, Baltimore, and Savannah facilities are located within 1.6 km (one mile) of wetlands (defined here to include swamps, marshes, bogs, and other similar areas). Wetlands are commonly entitled to special protection because they create habitats for many forms of wildlife, purify natural water, provide flood and storm damage protection, and afford a number of other benefits. Contamination from titanium wastes produced at these sites could potentially cause adverse effects in adjacent wetlands.

- The Ashtabula facility is located in a fault zone. Although unlikely, there is some potential for earthquake damage to the in-situ and recompacted clay liner of the on-site surface impoundment, potentially allowing greater-than-expected releases of waste solids contaminants to the subsurface.
- The New Johnsonville facility is located within 1.6 km (one mile) of a National Park. Based on the preceding analysis of the release, transport, and exposure potential of this facility, it is possible for waste solids contaminants to be blown into the air as dust from the on-site landfill (the potential for significant releases to ground water and surface water appears to be low). Any windblown contaminants produced from this landfill could potentially cause adverse effects on the habitats and resources provided by the National Park.
- The Savannah facility is located within 1.6 km (one mile) of a National Wildlife Refuge. Based on the preceding analysis of potential release, transport, and exposure pathways, there is a moderate potential for releases of waste solids contaminants from this site to ground water, surface water, and air. Any contaminants released from this site could potentially cause adverse effects on the habitats and resources provided by the National Wildlife Refuge.
- The Henderson facility is located within 1.6 km (one mile) of a National Recreation Area. As discussed in the preceding section, the primary potential release pathway at this facility is windblown dust from the on-site waste pile. Any airborne contaminants released from this waste pile could conceivably cause adverse effects on the habitats and resources provided by the National Recreation Area.

Risk Modeling

Based on the preceding analysis of the intrinsic hazard of chloride process waste solids and the potential for contaminants from the solids to be released into the environment, EPA ranked the waste solids as having a relatively high potential at some facilities to cause human health and environmental risks (compared to the other mineral processing wastes studied in this report). Therefore, the Agency used the model "Multimedia Soils" (MMSOILS) to estimate ground-water, surface water, and air risks caused by the existing waste solids management practices. Rather than model all nine facilities that currently generate and manage the solids, EPA modeled only those facilities and release/exposure pathways that appear to pose the greatest concern in order to develop reasonable upper bound estimates of the risks across the industry.

Ground-Water Risks

EPA modeled potential releases to ground water from the surface impoundments used to accumulate waste solids at the Kerr-McGee facility in Hamilton, MS. This facility was selected for ground-water modeling because it appears to have the highest ground-water release and exposure potential of all the active titanium tetrachloride facilities, based on the above analysis of management practice and environmental setting characteristics. Using median contaminant concentrations measured in waste solids from the other titanium facilities,¹⁵ combined with site-specific data with respect to waste solid quantities, impoundment design features, and hydrogeologic characteristics at the Hamilton facility, EPA predicted the concentrations of nine constituents (arsenic, chromium, cobalt, copper, iron, lead, manganese, nickel, and silver) at a variety of downgradient locations. The downgradient distances that were modeled included the property boundary and nearest surface water body (60 meters), the nearest existing residence that could have a drinking water well (700 meters), and, to analyze how far the contaminant plume might migrate, a distance of 1,000 meters. For each constituent, the Agency compared the predicted concentrations at these locations to cancer risk levels, threshold concentrations for noncancer effects, drinking water maximum contaminant levels (MCLs), and guidelines for irrigation and livestock waters recommended by the National Academy of Sciences (NAS).

¹⁵ No data are available on the composition of waste solids at the Hamilton facility.

For all of the constituents except arsenic and cobalt, the predicted concentrations at each of the downgradient distances modeled (including the property boundary roughly 60 meters downgradient) were at least two orders of magnitude below the various criteria. The predicted concentration of arsenic at the property boundary poses a lifetime cancer risk of 3×10^{-4} (i.e., the chance of getting cancer would be approximately 3 in 10,000 if the water was ingested over a 70-year lifetime). This predicted arsenic concentration, however, is only 0.2 times the MCL. It is unlikely that anyone would actually drink the ground water at or very near the property boundary at this facility because the impoundments border McKinley Creek, and it is unlikely that anyone would place a drinking water well between the impoundments and McKinley Creek. The nearest existing residence that conceivably could have a drinking water well is located about 700 meters downgradient. Assuming that the ground water leaving the Hamilton site migrates beneath McKinley Creek and eventually to this residence, rather than discharging directly into the creek, the concentration of arsenic at this distant location would pose a very low lifetime cancer risk, less than 1×10^{-10} .

The predicted concentration of cobalt did not exceed any of the criteria at any of the downgradient distances, but it was equal to 0.8 times the NAS guideline for irrigation water at the property boundary. Concentrations of cobalt in excess of this guideline have been shown to be toxic to a variety of plants, including tomatoes, peas, beans, oats, rye, wheat, barley, and corn. Although the Hamilton site is located in an agricultural area, this cobalt contamination is not likely to cause significant impacts because: the maximum predicted concentration at a point where the ground water conceivably could be used is below the criterion, the contamination may discharge directly into McKinley Creek where it would be further diluted, and the predicted concentration of cobalt in ground water at the nearest downgradient residence that could have a well is more than two orders of magnitude below the NAS guideline.

As a "worst-case" analysis, EPA estimated the downgradient concentrations of chromium and lead assuming that the waste solids leachate from the impoundments at Hamilton contain the highest concentrations observed in any of the available sample results, 100 mg/l chromium and 31 mg/l lead. This chromium concentration exceeds the EP toxic level by a factor of 20 and the lead concentration exceeds the EP toxic level by a factor of 6. Even when these maximum leachate concentrations were used, the ground-water concentrations of both chromium and lead at the property boundary were predicted to be more than two orders of magnitude below their respective criteria.

Surface Water Risks

To evaluate surface water risks, EPA again considered the Kerr-McGee facility in Hamilton, MS. Having large impoundments within 60 meters of a creek, this facility has a relatively high potential (compared to the other eight titanium facilities) of contaminating surface water via releases to ground water. In order to assess the possible combined effect of stormwater erosion into surface water, the Agency conservatively assumed that, after closure, the impoundments were filled with waste solids but not covered or equipped with run-off controls.

Using this conservative scenario, EPA predicted the concentration of the following waste solid contaminants in McKinley Creek after they have been fully mixed in the creek's flow: arsenic, chromium, cobalt, copper, iron, lead, manganese, nickel, silver, and thallium. For each constituent, the Agency compared the predicted concentrations to cancer risk levels, threshold concentrations for noncancer effects, drinking water MCLs, freshwater ambient water quality criteria, and the NAS recommended guidelines for irrigation and livestock. Note that the methodology used here does not account for removal of pollutants via drinking water treatment, and thus overstates the risk through that pathway.

Even with this conservative approach, EPA's risk model predicted that the average annual flow of McKinley Creek is capable of effectively assimilating the annual load of contaminants from the on-site impoundments. The predicted concentrations of all the constituents were more than two orders of magnitude below the various criteria. The predicted concentration of arsenic in the creek would pose a very low lifetime cancer risk, about 1×10^{-8} , and is more than five orders of magnitude below the MCL. With the exception of arsenic and cobalt, essentially 100 percent of the contamination in McKinley Creek was predicted to be caused by the erosion of fine particles of the waste solids (seepage of contaminants into ground water with subsequent discharge into the creek resulted in a negligible pollutant loading). For arsenic and cobalt, approximately 80 percent of the contaminant load to the stream was through ground-water discharge, while only 20 percent was due to erosion.

As was done in the assessment of ground-water risks, EPA analyzed how these risk estimates would change if, instead of using median contaminant concentrations, the concentrations of chromium and lead in leachate from the impoundment were assumed to equal the maximum concentrations observed in EP leach tests (which exceeded the EP-toxic levels). Using these maximum concentrations would increase the loading of chromium to the creek, but not enough to make the surface water concentration approach hazardous levels. Similarly, increasing the lead concentration in the leachate had no effect on the predicted concentration in McKinley Creek because essentially all of the lead contamination was predicted to enter the creek by erosion rather than seepage through ground water.

None of the constituents that were modeled are recognized as having the potential to biomagnify (concentrate in the tissue of organisms higher in the food chain). Arsenic and chromium can bioaccumulate slightly in the tissue of freshwater fish that may be ingested by humans. However, even under worst-case exposure assumptions, the predicted concentrations of these contaminants are very unlikely to cause adverse health effects through the fish ingestion pathway.

Air Risks

To analyze air risks, EPA modeled the release of windblown dust from the waste solids pile and the associated inhalation risks at the facility in Henderson, NV. Of the nine active titanium facilities, this facility has the greatest potential to pose air risks because the solids are managed in a large pile that is uncovered, exposed to relatively high winds, and dry most of the time (as described in the above analysis of release, transport, and exposure potential). There is also a residence located just 90 meters downwind and 5,000 people live within one mile; all could be exposed to any windblown dust. Using the median constituent concentrations and site-specific data with respect to waste quantities, existing management practices, and atmospheric dispersion conditions, EPA estimated the release and inhalation risks of arsenic, chromium, thorium-232, and uranium-238, which are the primary constituents of concern through the air pathway, based on the preceding analysis of the waste solids' composition.

At the residence of the maximum exposed individual (roughly 90 meters downwind from the waste pile), EPA predicted airborne concentrations of arsenic, chromium, thorium-232, and uranium-238. Total lifetime cancer risk, from all four constituents combined, is 1×10^{-8} . Most of this risk was estimated to be caused by chromium, conservatively assumed here to exist in its carcinogenic hexavalent form. If the maximum waste solids concentrations of these constituents were used in the model instead of median concentrations, the total lifetime cancer risk would be 2×10^{-7} ; this represents the maximum inhalation risk expected across the industry. The predicted concentrations of these contaminants 800 meters (0.5 mile) downwind in the predominant wind direction poses a lifetime cancer risk of 3×10^{-9} . This risk approximates the average inhalation risk of the 5,000 people living within 1.6 km (1 mile) of the facility.

13.3.2 Damage Cases

State and EPA regional files were reviewed in an effort to document the performance of waste management practices for chloride process waste solids from titanium tetrachloride production at the active titanium facilities, and at two inactive titanium facilities: Ormet in Albany, Oregon; and duPont in La Porte, Texas.¹⁶ The file reviews were combined with interviews with State and EPA regional regulatory staff. Through these case studies, EPA found no documented environmental damages clearly attributable to management of chloride process waste solids from titanium tetrachloride production at any of these facilities. Some cases of documented damage attributable to other wastes were identified, however, and it is possible, though not demonstrated, that waste solids have contributed to these observed damages.

13.3.3 Findings Concerning the Hazards of Chloride Process Waste Solids

¹⁶ Facilities are considered inactive for purposes of this report if they are not currently engaged in primary mineral processing.

Available data on the composition of the waste solids show that the solids contain over 17 constituents that are present in concentrations that exceed the screening criteria. The contaminants that appear to pose the greatest potential threat are arsenic, chromium, iron, lead, manganese, vanadium, and silver. Based on available data and professional judgment, EPA does not believe that the waste solids exhibit the hazardous waste characteristics of corrosivity, ignitability, or reactivity. However, using the EP leach test, chromium exceeded the EP toxicity regulatory level in 3 of 16 samples, and lead exceeded the EP toxicity regulatory level in 1 of 16 samples. Lead and chromium concentrations measured using the SPLP test also exceeded the EP toxicity regulatory levels, by roughly the same margin as the EP test results. In addition, the waste solids contain uranium-238, thorium-232, and their decay products in concentrations that could pose an unacceptably high radiation risk if the solids were allowed to be used in an unrestricted fashion.

Based on an examination of the characteristics of each site, EPA believes that there is a potential for waste solids contaminants to migrate into ground-water, surface water, and air at the active titanium facilities. For example:

- There is a relatively high potential for ground-water contamination from the impoundments at the Antioch, CA and Hamilton, MS facilities because the solids are submerged beneath liquids that could hydraulically force contaminants into the subsurface, some of the impoundments may not be equipped with liners or leachate collection systems, the ground water is shallow (1 to 6 m deep), and the subsurface is highly permeable.
- Most of the facilities are located within 100 meters of a river or creek. At those sites with a relatively high ground-water release potential, it is likely that any ground-water contamination would discharge directly into these water bodies. In addition, the particle size of the solids is fairly small and thus it is possible for contaminants to erode into nearby creeks and rivers when the solids are managed in landfills and waste piles.
- The small particle size of the solids is conducive to wind erosion and transport, and the solids are managed at four facilities in piles or landfills that are exposed to the wind. The potential for such airborne releases appears greatest at the waste solids pile at the Henderson, NV facility, where the solids are expected to remain dry most of the time and winds are relatively strong.

However, based on site-specific modeling results, the Agency predicts that the environmental contamination that could occur is not likely to cause significant adverse impacts, as currently managed at the existing facilities. This is corroborated by the lack of documented cases of damage attributable to the waste solids at the existing facilities. The environmental conditions at the Hamilton facility are most conducive to ground- and surface water contamination. Using these facility conditions as the basis for modeling, EPA predicts that the concentration of arsenic in ground water at the plant boundary (roughly 60 meters downgradient) could pose a lifetime cancer risk of 3×10^{-4} . In terms of current exposures, however, nobody presently drinks the ground water at this location, and the predicted arsenic concentration at the nearest existing residence that could have a drinking water well would pose a cancer risk of less than 1×10^{-10} . Any contamination of the water table aquifer at this site and any stormwater run-off are likely to discharge directly into adjacent McKinley Creek. The predicted annual average concentrations of arsenic and other contaminants in this creek are more than two orders of magnitude below various hazard criteria. EPA believes the ground-water and surface water risks at the other titanium facilities would be comparable if not lower than those predicted for the Hamilton facility.

At the Henderson, NV facility, EPA predicts a maximum lifetime cancer risk of 2×10^{-7} caused by the release and inhalation of windblown dust. Again, the inhalation risks at the other facilities are probably even lower.

13.4 Existing Federal and State Waste Management Controls

13.4.1 Federal Regulation

Under the Clean Water Act, EPA has the responsibility for setting "effluent limitations," based on the performance capability of treatment technologies. These "technology based limitations," which provide the basis for

the minimum requirements of NPDES permits, must be established for various classes of industrial discharges, including a number of ore processing categories.

Permits for mineral processing facilities may require compliance with effluent guidelines based on best practicable control technology currently available (BPT) or best available technology economically achievable (BAT). BPT effluent limitation guidelines relevant to discharges from the production of titanium dioxide by oxidizing titanium tetrachloride include:

TITANIUM DIOXIDE-CHLORIDE PROCESS (40 CFR 415.222(b))		
Pollutant	Daily Maximum	Monthly Average
Total Suspended Solids	23 Kg/kkg	6.4 Kg/kkg
Total Chromium	0.057 Kg/kkg	0.030 Kg/kkg
pH	6 - 9	6 - 9

TITANIUM DIOXIDE-CHLORIDE-ILMENITE PROCESS (40 CFR 415.222(c))		
Pollutant	Daily Maximum	Monthly Average
Total Suspended Solids	35 Kg/kkg	9.6 Kg/kkg
Total Chromium	0.12 Kg/kkg	0.053 Kg/kkg
Total Nickel	0.072 Kg/kkg	0.035 Kg/kkg
pH	6 - 9	6 - 9

BAT effluent limitation guidelines for the above mentioned processes require that discharges not exceed the limitations set forth for chromium in 40 CFR 415.222 (b) and (c), and further that the discharge of nickel not exceed the levels established in 40 CFR 415.222 (c) for the dioxide-chloride-ilmenite process.

New source performance standards for these two processes include the following limitations (40 CFR 415.225 (b) and (c)):

TITANIUM DIOXIDE-CHLORIDE PROCESS		
Pollutant	Daily Maximum	Monthly Average
Total Suspended Solids	14 Kg/kkg	4 Kg/kkg
Total Iron	0.52 Kg/kkg	0.016 Kg/kkg
Total Chromium	0.023 Kg/kkg	0.012 Kg/kkg
pH	6 - 9	6 - 9

TITANIUM DIOXIDE-CHLORIDE-ILMENITE PROCESS		
Pollutant	Daily Maximum	Monthly Average
Total Suspended Solids	8.4 Kg/kkg	2.4 Kg/kkg

Total Iron	0.32 Kg/kkg	0.096 Kg/kkg
Total Chromium	0.014 Kg/kkg	0.0072 Kg/kkg
Total Nickel	0.020 Kg/kkg	0.010 Kg/kkg
pH	6 - 9	6 - 9

13.4.2 State Regulation

The nine facilities in the titanium tetrachloride sector generating chloride process waste solids are located in eight states: California, Delaware, Georgia, Maryland, Mississippi, Nevada, Ohio, and Tennessee. For the purposes of this report, four of these states, Delaware, Mississippi, Ohio, and Tennessee, were studied in detail (see Chapter 2 for a discussion of the methodology used to select states for detailed regulatory study). Two facilities are located in Mississippi, while a single facility is located within each of the three remaining study states.

As a general overview, all of the eight states with titanium tetrachloride facilities except California exclude mineral processing wastes from their hazardous waste regulations. California has hazardous waste provisions for mine and mill tailings under certain circumstances, though it is not clear whether the state applies these provisions to the chloride process waste solids generated within its borders. Of the study states, Delaware, Tennessee, and Ohio have solid waste regulations that address and regulate the disposal of solid wastes from mineral processing, while Mississippi exempts on-site disposal of industrial solid waste from any requirements under the state's solid waste regulations. All four of the study states have approved NPDES programs and issue permits for all point-source discharges to surface waters. All four states also have air quality regulations, but none that are applicable to chloride process waste solids disposal practices.

Ohio and Tennessee each have a single titanium tetrachloride facility that generates chloride process waste solids.¹⁷ The solid waste regulations of both of these states apply to mineral processing wastes. Because Ohio's regulations include exemptions for wastes that are reused or recycled, however, the state has not required a solid waste permit of the Ashtabula facility, which recycles all of its chloride process waste solids that are not shipped off-site for disposal. Ohio's regulations do not include specific storage requirements for non-putrescible wastes, regardless of the storage time before the waste is actually recycled. Similarly, although Tennessee requires its titanium tetrachloride facility to maintain a solid waste disposal permit, the state has focused its regulatory efforts primarily on municipal solid waste landfills. Both Ohio and Tennessee recently revised their regulations and appear to be preparing to regulate mineral processing wastes more comprehensively. If the states implement the regulations as anticipated, both titanium tetrachloride facilities could be required to upgrade their disposal management practices to include activities such as the installation of covers, liners, and ground-water monitoring, or to ship their wastes off-site to properly permitted landfills. Both Ohio and Tennessee have approved NPDES programs and require permits for all discharges to surface waters. Finally, neither Ohio nor Tennessee has applied fugitive dust emission controls to their facilities' chloride waste solids disposal activities.

Two titanium tetrachloride facilities are active in the State of Mississippi. Mississippi's solid waste regulatory program exempts mineral processing wastes that are generated, processed, and disposed of on-site. Because both of Mississippi's facilities dispose of their chloride process waste solids on-site, therefore, neither facility has been required to obtain a solid waste disposal permit. Mississippi does have an approved NPDES program, however, and requires NPDES permits of both facilities that include provisions for effluent monitoring/characterization. One of the facilities is permitted to discharge its process wastewater to surface waters while the second facility injects its process wastewater into the ground via three on-site deep wells. Mississippi has not applied fugitive dust emission control requirements to the chloride waste disposal activities of its titanium tetrachloride facilities.

¹⁷ Ohio's SCM facility at Ashtabula actually consists of two plants, Ashtabula I and II.

A single facility is active in the State of Delaware. Of the four study states, Delaware appears to most active in regulating its single titanium tetrachloride facility under its solid waste regulations. The state has required that the facility maintain a permit and meet a variety of environmental criteria such as the collection, treatment, and disposal of leachate and the installation of liners. Delaware recently revised its solid waste regulations, though the changes appear to be more administrative than substantive. As with the other study states, Delaware has an approved NPDES program and has required that the facility maintain a discharge permit for its on-site surface impoundment. Finally, as with the other study states, Delaware has not applied fugitive dust emission controls to its facilities' chloride process solid waste disposal activities.

In summary, all of the four study states with titanium tetrachloride facilities exclude the management and disposal of chloride process waste solids from hazardous waste regulation. Of these four states, Delaware appears to be most actively regulating these wastes under its solid waste regulations. In contrast to apparently limited regulation in the past, however, both Ohio and Tennessee recently revised their solid waste regulations and appear to be preparing to regulate these wastes more stringently. All four study states have approved NPDES programs and have applied permit requirements to the titanium tetrachloride facilities within their borders that discharge to surface waters. Finally, none of the states apply fugitive dust emission controls to the disposal of chloride process waste solids.

13.5 Waste Management Alternatives and Potential Utilization

In the following paragraphs, the Agency provides a brief summary of information collected on alternative waste management practices and potential areas of utilization.

Recycling of the waste solids is the primary management alternative to the current disposal practice of neutralization and surface impoundment/landfill disposal. Laboratory tests have shown that the solid residue (approximately one-half of the sludge by weight) generated during the production of titanium tetrachloride from rutile, can be agglomerated and recycled. Recycling the solid residue would reduce the volume of waste requiring disposal, and there is reason to believe that the addition of the residue to the rutile charge could improve the chlorination characteristics of the feed materials.¹⁸ However, while many producers of titanium tetrachloride have tried to develop methods of recycling their waste solids, as of 1987, no facilities were reported to be routinely recycling their waste solids.¹⁹ Most facilities that have tried to recycle the waste solids have experienced operational difficulties (e.g., corrosion or reactor upsets) which caused them to abandon recycling.

Another management alternative is the recovery of columbium, tantalum, zirconium, and titanium from the waste solids. Laboratory tests have demonstrated the technical feasibility of recovering these metals (on a bench-scale) from the waste solids generated by the Timet (Henderson, Nevada), SCM (Ashtabula, Ohio), Kerr-McGee (Hamilton, Mississippi), and E.I. duPont (New Johnsonville, Tennessee) facilities. The process involves a combination of water leaching, pressure hydrolysis, and solvent extraction.²⁰ However, it is not known if this process is being used by any of the facilities, or if a full-scale application of the process would be technically or economically feasible at any of the titanium tetrachloride facilities.

13.6 Cost and Economic Impacts

Section 8002(p) of RCRA directs EPA to examine the costs of alternative practices for the management of the special wastes considered in this report. EPA has responded to this requirement by evaluating the operational changes that would be implied by compliance with three different regulatory scenarios, as described in Chapter 2. In reviewing

¹⁸ Merrill, C.C., M.M. Wong, and D.D. Blue, Beneficiation of Titanium Chlorination Residues: Preliminary Study, Report of Investigations 7221, Bureau of Mines, U.S. Department of Interior, 1969, p. 5.

¹⁹ Krispar Technologies, Inc., Study on Titanium Chlorination Solid Wastes, Minerals & Materials Research Division, Bureau of Mines, U.S. Department of Interior, October 30, 1987, p. 145.

²⁰ Merrill, C.C. and D.E. Couch, Separation of Columbium, Tantalum, Titanium, and Zirconium from Titanium Chlorination Residues, Report of Investigations 7671, Bureau of Mines, U.S. Department of Interior, 1970.

and evaluating the Agency's estimates of the cost and economic impacts associated with these changes, it is important to remember what the regulatory scenarios imply, and what assumptions have been made in conducting the analysis.

The focus of the Subtitle C compliance scenario is on the costs of constructing and operating hazardous waste land disposal units. Other important aspects of the Subtitle C system (e.g., corrective action) have not been explicitly factored into the cost analysis. Therefore, differences between the costs estimated for Subtitle C compliance and those under other scenarios (particularly Subtitle C-Minus) are less than they might be under an alternative set of conditions (e.g., if most affected facilities were not already subject to Subtitle C). The Subtitle C-Minus scenario represents, as discussed above in Chapter 2, the minimum requirements that would apply to any of the special wastes that are ultimately regulated as hazardous wastes; this scenario does not reflect any actual determinations or preliminary judgments concerning the specific requirements that would apply to any such wastes. Further, the Subtitle D-Plus scenario represents one of many possible approaches to a Subtitle D program for special mineral processing wastes, and has been included in this report only for illustrative purposes. The cost estimates provided below for the three scenarios considered in this report must be interpreted accordingly.

In accordance with the spirit of RCRA §8002(p), EPA has focused its analysis on impacts on the firms and facilities generating the special wastes, rather than on net impacts to society in the aggregate. Therefore, the cost analysis has been conducted on an after-tax basis, using a discount rate based on a previously developed estimate of the weighted average cost of capital to U.S. industrial firms (9.49 percent), as discussed in Chapter 2. Waste generation rate estimates (which are directly proportional to costs) for the period of analysis (the present through 1995) have been developed in consultation with the U.S. Bureau of Mines.

In this section, EPA first outlines the way in which it has identified and evaluated the waste management practices that would be employed under different regulatory scenarios by facilities producing titanium tetrachloride (dioxide). Next, the section discusses the cost implications of requiring these changes to existing waste management practices. The last part of the section discusses and predicts the ultimate impacts of the increased waste management costs faced by the facilities.

13.6.1 Regulatory Scenarios and Required Management Practices

Based upon the information presented above, EPA believes that waste solids generated in the production of titanium tetrachloride at some facilities exhibit the hazardous waste characteristic of EP toxicity. Accordingly, the Agency has estimated the costs associated with regulation under Subtitle C of RCRA, as well as with two somewhat less stringent regulatory scenarios, referred to here as "Subtitle C-Minus" and "Subtitle D-Plus," as previously introduced in Chapter 2, and as described in specific detail below.

EPA has adopted a conservative approach in conducting its cost analysis for the wastes generated by the titanium tetrachloride production industry. The Agency has assumed that the chloride process waste solids would exhibit EP toxicity at all facilities unless actual sampling and analysis data demonstrate otherwise. EPA's waste sampling data indicate that the waste solids do not exhibit any characteristics of hazardous waste at five of the nine facilities that generate the material. The Agency's cost and impact analysis is therefore limited to four facilities.

Subtitle C

Under Subtitle C standards, generators of hazardous waste that is managed on-site must meet the rigorous standards codified at 40 CFR Part 264 for hazardous waste treatment, storage, and disposal facilities. Because chloride process waste solids are solid (sludge), non-combustible materials, and because under full Subtitle C regulation, hazardous wastes cannot be permanently disposed of in waste piles, EPA has assumed in this analysis that the ultimate disposition of chloride process waste solids would be in Subtitle C landfills, either on-site or, if sites for land disposal are not available, off-site. Because chloride process solids are typically generated as a sludge following treatment or settling in an impoundment and because of restrictions concerning liquids in landfills, the Agency has assumed that the facilities would also construct storage surface impoundments (two per facility) to manage the sludge and prepare it for disposal. Each impoundment is assumed to have the capacity to hold one half of the waste generated annually. These impoundments would be used to settle the solids; periodically (collectively for half the year) solids are settled in one of

the two impoundments. The remainder of the year the solids are routed to the second impoundment, while the sludge in the first impoundment is dried and stabilized with cement. The stabilized sludge is then dredged and landfilled. Facilities that currently ship their waste solids off-site for disposal (e.g., SCM-Ashtabula) are assumed to construct their own on-site waste management units, because this would be considerably less costly than shipment of the chloride process waste solids to a commercial hazardous waste management facility, given the volumes of waste involved.

Subtitle C-Minus

A primary difference between full Subtitle C and Subtitle C-Minus is the facility-specific application of requirements based on risk potential at each site. Under the C-Minus scenario, as well as the Subtitle D-Plus scenario described below, the degree of potential risk of contaminating ground-water resources was used as a decision criterion in determining what level of design standards (e.g., liner and closure cap requirements) would be necessary to protect human health and the environment. All four facilities generating potentially hazardous chloride process waste solids were determined to have a high potential to contaminate ground-water resources. When risk to ground water is high, facilities are assumed to be required to manage the waste in disposal impoundments equipped with composite liners. As none of the facilities currently operate adequately lined disposal units, all four facilities would be required to build new units under the Subtitle C-Minus scenario. In addition to the composite liners, the facilities are required to install run-on/run-off controls and groundwater monitoring wells; both practices must be continued through the post-closure care period. In addition, the units must undergo formal closure, including a cap of topsoil and grass/synthetic liner/clay (three foot thickness). Post-closure care must be maintained (e.g., mowing and general cap maintenance, and groundwater monitoring) for a period of thirty years.

In addition to the cost differences between full Subtitle C and Subtitle C-Minus that are attributable to the design, construction, and operation of waste management units, a potentially significant cost difference arises from the relaxation of the sludge stabilization/solidification step that EPA has included in the full Subtitle C scenario to account for probable future Land Disposal Restrictions. Under the Subtitle C-Minus scenario, sludges are assumed to be disposed without stabilization/solidification. This implies a savings of the treatment equipment and variable costs, and the cost of disposing the greater (50 percent) quantity of stabilized material, in comparison with the full Subtitle C scenario. In addition, the treatment (i.e., settling) ponds used to separate sludge and entrained water prior to cementation are no longer required.

Subtitle D-Plus

As under both Subtitle C scenarios, facility operators under the Subtitle D-Plus scenario would be required to ensure that hazardous contaminants do not escape into the environment. Like the Subtitle C-Minus scenario, facility-specific requirements are applied to allow the level of protection to increase as the potential risk to groundwater increases. Because the four titanium tetrachloride facilities with potentially hazardous chloride process waste solids all have high potential to contaminate groundwater resources, the facilities are assumed to require disposal in impoundments lined with composite liners, which, as pointed out above, none of the facilities currently have. Therefore, EPA has assumed that the facilities would construct new units with composite liners, and install run-on/run-off controls and groundwater monitoring wells; maintenance of these systems must be continued through the post-closure care period under this scenario, as in the others. In addition, the units must undergo formal closure, including a cap of topsoil and grass over a synthetic liner on three feet of clay. Post-closure care must be maintained (e.g., leachate/run-off collection and treatment, cap maintenance, and groundwater monitoring) for a period of thirty years. Under this scenario, EPA has assumed that the SCM-Ashtabula facility would be required to construct on-site management units that meet the Subtitle D-Plus technical standards, rather than continue to ship its chloride process waste solids off-site for disposal. In this way, adequate protection of human health and the environment would be ensured.

As in the Subtitle C-Minus scenario, EPA has not included a sludge stabilization/solidification step in the waste management sequence. This results in considerable savings over waste management under the full Subtitle C scenario.

13.6.2 Cost Impact Assessment Results

Results of the cost impact analysis for the titanium tetrachloride sector are presented by facility and regulatory
s c e n a r i o i n E x h i b i t 1 3 - 6

. Under the Subtitle C scenario, annualized incremental regulatory compliance costs for the sector are estimated at more than \$28.0 million. The costs range from \$5.4 to \$9.4 million greater than baseline costs (4 to 29 times larger than baseline). Annualized capital costs range from \$2.4 to \$4.9 million over baseline, representing about one half of the total annual costs. Total initial compliance-related capital expenditures are \$98.8 million, ranging from \$16.0 million to \$33.2 million.

Under the facility-specific requirements of the Subtitle C-Minus scenario, costs of regulatory compliance are, for the sector, about eleven percent of the full Subtitle C costs. The sector-wide annualized compliance cost is about \$3.2 million greater than baseline (roughly twice the baseline costs). Total initial capital costs are estimated at about \$24.8 million, ranging from \$3.0 to \$7.9 million. Overall, the primary differences in costs are due to decreased capital construction costs and relaxation of the sludge stabilization/solidification requirements; the difference in capital costs is primarily related to the configuration of the landfill liners, leachate collection/detection systems, and closure caps. Other waste management elements having significant cost implications (e.g., non-liner related capital construction costs, operating costs, ground-water monitoring) are identical under these two regulatory scenarios.

Costs under the Subtitle D-plus regulatory scenario are virtually identical to those under Subtitle C-minus scenario, the only difference being slight difference in permit costs at one facility.

13.6.3 Financial and Economic Impact Assessment

To evaluate the ability of affected facilities to bear these regulatory compliance costs, EPA conducted an impact assessment consisting of three steps. First, the Agency compared the estimated costs to several measures of the financial strength of each facility and thereby generated financial impact ratios, to assess the magnitude of the financial burden that would be imposed in the absence of changes in supply, demand, or price. Next, in order to determine whether compliance costs could be distributed to (shared among) other production input and product markets, EPA conducted a qualitative evaluation of the salient market factors that affect the competitive position of domestic producers. Finally, the Agency combined the results of the first two steps to arrive at predicted ultimate compliance-related economic impacts on the titanium tetrachloride (dioxide) industry. The methods and assumptions used to conduct this analysis are described in Chapter 2.

Financial Ratio Analysis

EPA believes that Subtitle C regulation would impose potentially significant financial impacts on all four potentially facilities in the titanium tetrachloride industry. As shown in Exhibit 13-7, the annualized capital costs associated with waste management under Subtitle C as a percentage of annual investment exceed the five percent threshold at all four facilities, ranging from 18 to 49 percent. Annualized incremental costs as a percentage of value of shipments and value added exceed the screening criteria for significant impacts in all cases; these ratios range from just under 2.0 percent to 5.3 percent.

Financial impacts under the Subtitle C-Minus scenario are significantly lower than under full Subtitle C. The annualized capital costs associated with waste management under Subtitle C-Minus as a percentage of annual investment again exceed the five percent threshold for three of the four affected firms. Annualized incremental costs as a percentage of value of shipments and value added continue to exceed the threshold for potentially significant impacts only at the Timet facility where costs ratio results are just over one percent.

Under the Subtitle D-Plus scenario, as discussed above, costs, and therefore impacts, are nearly identical to those under the Subtitle C-Minus scenario.

Market Factor Analysis

General Competitive Position

The U.S. is very competitive in titanium dioxide production on a worldwide basis. Some of the producers, such as duPont, are also partially integrated through the raw material stage. The fact that very few producers worldwide are fully integrated (with the exception of Norway and some Australian producers) puts manufacturers on a roughly equal basis in terms of raw material costs. Indeed, the fact that most producers are largely dependent on Australian rutile, ilmenite, and titaniferrous slags has led to strong price increases for these raw materials over the last ten years. The U.S. plants that previously produced titanium dioxide by the higher cost sulfate route have largely been eliminated or updated.

In terms of conversion to the chloride process, the U.S. is considerably more advanced than other countries and therefore will not undergo the capital expenditures for conversion that many other countries will likely be required to make over the next decade in order to remain cost-competitive. The fact that the U.S. is efficient (has comparatively low processing costs) and also a pioneer of chloride process technology (most notably duPont) results in the U.S. being very competitive on a worldwide basis.

Exhibit 13-7
Significance of Regulatory Compliance Costs for Management of
Titanium Tetrachloride Chloride Process Waste Solids^(a)

Facility	CC/VOS	CC/VA	IR/K
Subtitle C			
duPont - New Johnsonville, TN	1.7%	1.9%	18.0%
SCM Chemicals - Ashtabula, OH	2.5%	3.2	33.6%
Kerr-McGee - Hamilton, MS	3.2%	4.1%	28.2%
Timet - Henderson, NV	5.1%	5.3%	49.0%
Subtitle C-Minus			
duPont - New Johnsonville, TN	0.0%	0.0%	4.3%
SCM Chemicals - Ashtabula, OH	0.3%	0.3%	9.1%
Kerr-McGee - Hamilton, MS	0.5%	0.7%	5.3%
Timet - Henderson, NV	1.1%	1.2%	14.2%
Subtitle D-Plus			
duPont - New Johnsonville, TN	0.0%	0.0%	4.3%
SCM Chemicals - Ashtabula, OH	0.3%	0.3%	9.1%
Kerr-McGee - Hamilton, MS	0.5%	0.7%	5.3%
Timet - Henderson, NV	1.1%	1.1%	14.2%
CC/VOS = Compliance Costs as Percent of Sales CC/VA = Compliance Costs as Percent of Value Added IR/K = Annualized Capital Investment Requirements as Percent of Current Capital Outlays (a) Values reported in this table are based upon EPA's compliance cost estimates. The Agency believes that these values are precise to two significant figures.			

Potential for Compliance Cost Pass-Through

Labor Markets

There is a possibility for some reduction in wages, as past reductions in salary have not been comparable to that of the general mineral processing industry. The need to keep highly-skilled professionals (to maintain and expand the technological advantage of domestic producers), however, means that lower wages may cause personnel losses to competitors in other chemical industry segments.

Supply Markets

The U.S. does utilize some ilmenite, even though most plants have converted to the chloride process, which cannot use ilmenite directly as a feedstock (the sulfate process can use ilmenite directly). A large portion of the ilmenite brought to the U.S. is as a feedstock for the Kerr-McGee synthetic rutile plant in Hamilton, Mississippi, and is obtained under long-term contract.

DuPont also utilizes some ilmenite in its process, even though it uses chloride route processing, but these are largely altered ilmenites from domestic and imported (long-term contract) sources. Most U.S. plants need slag, rutile, or synthetic rutile as a feedstock. Consequently, U.S. pigment producers may be able to moderate titanium raw material price increases, but have little power to lower prices (pass compliance costs backwards).

Higher Prices

As the U.S. is a principal world producer, and foreign capacity is limited, there has been leeway to raise prices in past years. For this reason, the price of titanium dioxide pigment has already risen significantly over the last several years. There is a limit to price elasticity, however, particularly in the paper industry, where competitive materials replace (or limit) the use of titanium dioxide in some applications. The paper industry is striving to reduce consumption of titanium dioxide because of the high price levels. This has been done, particularly in plants using alkaline paper making, by increasing calcium carbonate use as a titanium dioxide extender. Although more difficult to replace in paint applications, a reduction and rationalization is a possibility if prices continue to rise.

Additional capacity worldwide will also tend to limit price increases beyond 1990. The U.S. itself produces a limited amount of raw materials to supply internal titanium dioxide requirements, and these would not be economic for export on the world market, as they simply are partial feedstocks for integrated producers.

Evaluation of Cost/Economic Impacts

EPA estimates that three and possibly a fourth of the nine facilities domestically producing titanium tetrachloride would face significant impacts under full Subtitle C regulation. Costs and impacts under the nearly identical Subtitle C-Minus and D-Plus scenarios are not expected to significantly affect any facilities; only one facility, Timet/Henderson, is expected to have costs higher than one percent of value of shipments or value added.

In terms of distributing costs, it seems likely that some of the costs that would be incurred under these scenarios might be passed on in the form of higher prices. If, however, only three or four facilities are affected out of a total of nine (or a total of 11 or 12 facilities that may be operating during the next two years) increasing prices will be less likely. Also, because prices have already increased during the past few years, and because these higher prices are reducing demand for titanium dioxide (the primary product from processing the titanium tetrachloride), the industry may not be able to raise prices enough to fully recover compliance costs. In addition, within several years, additional domestic capacity is expected to become operational making increases in prices in order to pass on compliance costs very difficult.

Given the moderate nature of the prospective cost impacts of modified Subtitle C and Subtitle D regulation, and the healthy and globally competitive position of domestic titanium tetrachloride producers, EPA does not believe that potential regulatory compliance costs under the RCRA Subtitle C-Minus scenario would impose significant economic impacts upon affected facilities. Although these costs would not be shared among all domestic producers (affected facilities account for approximately 26 percent of domestic capacity), and therefore, affected facilities might be put at a competitive disadvantage with respect to other domestic producers, the Agency does not believe that the long-term profitability and continued operation of these plants would be threatened by a decision to regulate chloride process waste solids under modified Subtitle C standards. In addition, adequately protective standards and their costs under a modified Subtitle C program are in many ways identical to the probable standards and costs that would result from Subtitle D regulation, suggesting that generators of this waste may face costs from modifying their existing waste management practices regardless of whether this waste remains within the Mining Waste Exclusion.

13.7 Summary

As discussed in Chapter 2, EPA developed a step-wise process for considering the information collected in response to the RCRA §8002(p) study factors. This process has enabled the Agency to condense the information presented in the previous six sections of this chapter into three basic categories. For the special waste generated by facilities in this commodity sector (chloride process waste solids), these categories address the following three major topics: (1) the potential and documented danger to human health and the environment; (2) the need for and desirability of additional regulation; and (3) the costs and impacts of potential Subtitle C regulation.

Potential and Documented Danger to Human Health and the Environment

The intrinsic hazard of the chloride process waste solids is relatively high (at some facilities) compared to the other mineral processing wastes studied in this report. Based on EP leach test results, 3 out of 16 samples (from 3 of 7 facilities tested) contain chromium concentrations in excess of the EP toxicity regulatory levels; lead was also measured in EP leachate in concentrations that exceed the regulatory level in 1 out of 16 samples (from 1 of 6 facilities tested). Chromium and lead concentrations measured in SPLP (EPA Method 1312) leachate also exceed the EP toxicity regulatory levels at one facility for which comparable SPLP test data are available. Moreover, the waste solids contain 12 constituents in concentrations that exceed the risk screening criteria used in this by more than a factor of 10. Nine of these constituents are metals that are expected to be relatively mobile if released to ground water, considering the acidic nature of the leachate. The waste solids may also contain uranium-238, thorium-232, and their decay products in concentrations that could pose an unacceptably high radiation risk if the solids were allowed to be used in an unrestricted manner. All of these factors lead EPA to conclude that the waste solids could present a significant hazard if mismanaged.

Based on an examination of existing release/exposure conditions at the nine active titanium tetrachloride facilities, EPA further concludes that management of the waste solids could allow contaminants to migrate into the environment, but that the potential for significant exposures to this contamination is currently low. For example, half of the facilities have a moderate to high potential for contaminants to migrate into ground water because they have large unlined surface impoundments and/or are underlain by shallow ground water, most facilities are adjacent to creeks or rivers into which contaminants might migrate, and the solids are susceptible to wind erosion when managed in uncovered piles or landfills. Based on predictive modeling for the "most sensitive" sites, EPA estimates that the concentrations of arsenic in ground water at the property boundary could pose a lifetime cancer risk as high as 3×10^{-4} . In terms of current exposures, however, nobody presently drinks the ground water at this location, and the predicted arsenic concentration at the nearest existing residence that could have a drinking water well would pose a cancer risk of less than 10^{-10} . The Agency's predicted concentrations of contaminants in surface waters near the sites are well below human health and environmental protection benchmarks. Similarly, EPA's predicted concentrations of windblown contaminants at locations of existing residences would pose a cancer risk of no more than 2×10^{-7} .

Based on the lack of documented cases of damage caused by the waste solids, it appears that the solids, as currently managed, have not caused significant human health or environmental impacts. State and EPA Regional files were reviewed and regulatory staff were interviewed in an effort to document the performance of waste management practices for chloride process waste solids at the nine active titanium facilities as well as two inactive facilities. Through these case studies, EPA found no documented environmental damages attributable to management of chloride process waste solids from titanium tetrachloride production at any of these facilities. Some cases of documented damage attributable to other wastes were identified at some titanium facilities, however, and it is possible, though not demonstrated, that waste solids have contributed to these observed damages.

Likelihood That Existing Risks/Impacts Will Continue in the Absence of Subtitle C Regulation

At several of the active facilities, the current waste management practices and environmental conditions may allow contaminant releases and risks in the future in the absence of more stringent regulation. For example, only 2 of the 15 impoundments and none of the landfills or waste piles used to manage the solids are equipped with either a synthetic liner or leachate collection system, even though usable ground water at many sites is relatively shallow (6 meters deep or less) and separated from the base of the units by relatively permeable earth materials. Many of the facilities are also located in humid areas with moderate to high rainfall and ground-water recharge rates, which can lead to contaminant migration. Similarly, none of the four facilities that manage the solids in waste piles or landfills practice any dust suppression, even though the waste solids are susceptible to wind erosion when managed in a dry form. Therefore, contaminant migration during the operating life of most units appears possible, and these releases could persist after closure if the units are not closed properly. Considering the intrinsic hazard of the waste, significant exposures to these releases could occur if nearby ground water is used.

The titanium tetrachloride production industry is also expected to expand in the future. The Bureau of Mines has reported that it expects an increase in titanium tetrachloride production capacity of approximately 600,000 metric tons by 1992 (current national production capacity is estimated to be 1.8 million metric tons per year). This increased production capacity likely will be made up by the addition of new facilities, for which management practices (in the absence of regulation) and environmental settings cannot be predicted at this time. Depending on the environmental characteristics of these sites, releases and risks could result if the waste solids are not properly managed.

The existing state regulatory programs appear to provide only limited control over the management of the waste solids, though they are growing more stringent in some states. With the possible exception of California, the eight states where titanium tetrachloride facilities are currently located exclude the waste solids from hazardous waste regulations. Based on a review of the regulatory programs in four states (Delaware, Mississippi, Ohio, and Tennessee), only Delaware appears to be regulating the waste solids extensively. The waste solids in Ohio and Mississippi are not subject to solid waste permit requirements, and Tennessee has focused its regulatory efforts on municipal solid waste problems rather than mining and mineral processing wastes. Delaware, Ohio, and Tennessee, however, have all recently adopted new regulations that could be used to address titanium waste solids and other mineral processing wastes more directly and comprehensively.

Costs and Impacts of Subtitle C Regulation

EPA has evaluated the costs and associated impacts of regulating this waste as a hazardous waste under RCRA Subtitle C. EPA's waste characterization data indicate that chloride process waste solids may exhibit the hazardous waste characteristic of EP toxicity at as many as four of the nine active facilities. Therefore, the Agency's cost and impact analysis is limited in scope to these four facilities, because the remaining five plants would not be affected by a decision to remove this waste from the Mining Waste Exclusion. These four plants in combination account for approximately 26 percent of domestic titanium tetrachloride production.

Costs of regulatory compliance exceed \$3 million annually, even under the least stringent (Subtitle D-Plus) scenario. Full Subtitle C regulation implies potentially significant economic impact at all four facilities, while application of the more flexible Subtitle C-Minus regulatory scenario would result in compliance costs that are approximately 75 percent lower. Costs under the Subtitle C-Minus and Subtitle D-Plus scenarios are almost identical, because adequately protective waste management unit design and operating standards are essentially the same under both scenarios, given the nature of the waste and the environmental settings in which it is currently managed. EPA's economic impact analysis suggests that the operators of potentially affected titanium tetrachloride plants could pass through a portion of any regulatory compliance costs that they might incur to product consumers. Demand for and prices of titanium dioxide, the principal end-product of titanium tetrachloride manufacturing, have been strong in recent years, as evidenced by the fact that four new domestic plants are projected to be on-line by 1992. Consequently, EPA believes that regulation of chloride process waste solids from titanium tetrachloride production under Subtitle C of RCRA would not threaten the long-term profitability or economic viability of any of the facilities that generate this waste.

Finally, EPA is not aware of any significant recycling or utilization initiatives that would be hampered by a change in the regulatory status of this waste. Recycling has been attempted in the past, but has not been operationally successful. There have also been attempts to recover tantalum, columbium, and other rare earth metals from the chloride process waste solids, but the techniques employed are at an early (bench-scale) stage of development.

Exhibit 13-6
Compliance Cost Analysis Results for Management of
Titanium Tetrachloride Process Waste Solids^(a)

Facility	Baseline Waste Management Cost	Incremental Costs of Regulatory Compliance								
		Subtitle C			Subtitle C-Minus			Subtitle D-Plus		
	Annual Total (\$ 000)	Annual Total (\$ 000)	Total Capital (\$ 000)	Annual Capital (\$ 000)	Annual Total (\$ 000)	Total Capital (\$ 000)	Annual Capital (\$ 000)	Annual Total (\$ 000)	Total Capital (\$ 000)	Annual Capital (\$ 000)
duPont - New Johnsonville, TN	2,023	9,496	33,217	4,956	142	7,914	1,181	142	7,914	1,181
SCM Chemicals - Ashtabula, OH	1,934	5,986	26,569	3,965	623	7,206	1,075	623	7,206	1,075
Ker-McGee - Hamilton, MS	591	5,448	16,086	2,400	896	3,018	450	896	3,018	450
Timet - Henderson, NV	365	7,134	22,981	3,429	1,545	6,645	992	1,540	6,645	992
Total:	4,913	28,064	98,853	14,750	3,206	24,783	3,698	3,201	24,783	3,698
Average:	1,228	7,016	24,713	3,688	801	6,196	924	800	6,196	924

(a) Values reported in this table are those computed by EPA's cost estimating model, and are included for illustrative purposes. The data, assumptions, and computational methods underlying these values are such that EPA believes that the compliance cost estimates reported here are precise to two significant figures.

Facilities modeled as generating potentially hazardous waste include those for which no sampling data exists.